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論 文 の 要 旨

Abstract of thesis

Aerobic granular sludge (AGS) including bacterial AGS (BAGS) and algal-bacterial AGS (A-BAGS) as promising alternatives for activated sludge (AS) has attracted more attention in recent years. However, the lack of fundamental research on AGS systems (especially for A-BAGS) still limits its wide application. As known, many ions like K^+ , Mg^{2+} , Ca^{2+} , etc. as the main ionic components of domestic wastewater are involved in the biological phosphorus removal (BPR) process. Although their effects on BPR have been widely studied in AS and BAGS systems, little information is available on A-BAGS due to the combined P removal mechanisms including polyphosphate-accumulating organisms (PAOs) uptake and algae uptake for growth. On the other hand, effective P removal from wastewater is of great concern due to water environment deterioration. Although highly effective P removal generally can be achieved through the enhanced biological phosphorus removal (EBPR) in which PAOs are the dominant species, the growth of PAOs is sensitive to environmental variations. Therefore, in this study, the response of main ions and mechanisms involved in BPR were compared and investigated in A-BAGS and BAGS (control). In addition, a novel EBPR strategy was proposed according to the main ionic behaviors in A-BAGS and BAGS-based sequencing batch reactors (SBRs).

This dissertation is divided into 5 chapters. In Chapter 1, the author gave a short literature review on the research background, including the development of AS and then the effects of main ions in domestic wastewater on AS granulation and nutrients removal. The objectives and thesis framework were finally summarized. In Chapter 2, the author examined the ionic response of A-BAGS system during BPR process. In both A-BAGS and BAGS systems, the major responsive ions were identified as Acetate (Ac^-), K^+ , Mg^{2+} and Ca^{2+} in wastewater rather than NH_4^+ , Na^+ , Cl^- and SO_4^{2-} , with the constant molar ratios of $\Delta P/\Delta Ac$, $\Delta K/\Delta P$ and $\Delta Mg/\Delta P$. Results show that the $\Delta P/\Delta Ac$ in A-BAGS under the absence of illumination was about 0.33, lower than 0.39 in BAGS, while it was negatively

influenced by the light density. It was estimated that about 62% of acetate was not utilized for P release at the high illuminance of 81 klux, indicating inhibited P release from PAOs. On the contrary, the molar $\Delta K/\Delta P$ and $\Delta Mg/\Delta P$ ratios were positively correlated with light density, which were increased from 0.43 and 0.34 (under the absence of illumination) to 0.63 and 0.39 (under the light density of 81 klux), respectively, reflecting that PO_4^{3-} , K^+ and Mg^{2+} were utilized by algae at different levels for their growth. In Chapter 3, the author investigated the feasibility of P-rich liquid separation from the bottom of SBRs during the non-aeration phase to stably enhance P removal by AGS-based SBRs. Results show that EBPR can be achieved in both A-BAGS and BAGS systems, with low effluent $PO_4^{3-}\text{-P} < 0.05$ mg/L after 3 days' operation. P balance analysis indicated that influent P contributed 95% and 97% of P in the P-rich liquids from A-BAGS and BAGS systems, respectively. The net P release from granules during the whole test period was detected to be about 5.23 ± 0.81 mg for BAGS and 9.11 ± 1.22 mg for A-BAGS in the experimental groups, which partially contributed to the P-rich liquid. In Chapter 4, the author explored the roles of ions played in the novel EBPR system. K^+ , Mg^{2+} and Ca^{2+} were the major responsive ions during the EBPR process. According to ions' compositions of P-rich liquids, the molar ratios of $\Delta K/\Delta P$ (0.28 in BAGS versus 0.31 in A-BAGS) and $\Delta Mg/\Delta P$ (0.28 in BAGS versus 0.28 in A-BAGS) were lower than the theoretical values (0.33) and the results calculated from the batch tests, suggesting partial K^+ and Mg^{2+} released were retained inside granules. The release of Ca^{2+} was identified with $PO_4^{3-}\text{-P}$ release during the non-aeration phase due to the following two reasons: (1) Mg^{2+} from hydrolysis of polyP may replace Ca^{2+} inside the granules based on ion exchange; and (2) Ca^{2+} may be released from the dissolution of $CaCO_3$ due to the decreased pH. In addition, it has been estimated by using Visual MINTEQ that the P-rich liquid has great potential for P recovery as Ca-P precipitates (especially in hydroxyapatite). In Chapter 5, the author summarized the major findings and proposed future research perspectives.

審 査 の 要 旨

Abstract of assessment result

This study proposed a novel operation strategy for EBPR by using BAGS and A-BAGS based on the roles of the main ions involved. The major responsive ions during BPR were identified as Ac^- , K^+ , Mg^{2+} and Ca^{2+} in both AGS systems, with constant molar ratios of $\Delta P/\Delta Ac$ (0.33), $\Delta K/\Delta P$ (0.43) and $\Delta Mg/\Delta P$ (0.34) under the absence of illumination. Under the strong illumination of 81 klux, the $\Delta P/\Delta Ac$ molar ratio decreased to 0.15 while the $\Delta K/\Delta P$ and $\Delta Mg/\Delta P$ molar ratios increased to 0.63 and 0.39, respectively, indicating less acetate for P release and more P for algae growth. The release of Ca^{2+} with P release was detected and attributable to the dissolution of $CaCO_3$ and ion exchange between Mg^{2+} and Ca^{2+} . Results indicate that EBPR can be stably realized through P-rich liquid separation in both A-BAGS and BAGS systems, producing high quality effluent with low $PO_4^{3-}\text{-P} < 0.05$ mg/L. The collected P-rich liquid can be easily used for P recovery and P recycling. More attention should be paid to the process stability during the long-term operation of the granular sludge system under the proposed strategy, and the effects on other functions of the wastewater treatment system as well.

The final examination committee conducted a meeting as a final examination on 12 July, 2021. The applicant provided an overview of the dissertation, addressed the questions and comments raised during Q & A session. All of the committee members reached a final decision that the applicant has passed the final examination.

Therefore, the final examination committee approved that the applicant is qualified to be awarded the degree of Doctor of Philosophy in Environmental Studies.